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AGARD ADVISORY REPORT No. 124

Technical Evaluation Report on the 51st (A) Specialists' Meeting of the Propulsion and Energetics Panel on Icing Testing for Aircraft Engines

by

D. Tedstone

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on the

51st (A) Specialists' Meeting

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PROPULSION AND ENERGETICS PANEL

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The Proceedings of the 51st (A) Specialists' Meeting of the Propulsion and Energetics Panel which was held at Church House, Westminster, London, UK on 3 and 4 April 1978 are published as AGARD Conference Proceedings CP 236, August 1978.

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TECHNICAL EVALUATION REPORT
ON
ICING TESTING FOR AIRCRAFT ENGINES

D.Tedstone

1. INTRODUCTION

The AGARD Propulsion and Energetics Panel, as part of the 51st Specialist Meeting at Church House, Westminister, London, England on April 3 and 4, 1978, held a two day specialist meeting on Icing Testing for Aircraft Engines.

The programme was arranged by a committee under the Chairmanship of Dr. J. Dunham of NGTE, UK and consisted of three sessions covering Requirements, Facilities and Instrumentation, and Experience. The meeting was attended by 73 observers representing the Aircraft Industry, various Universities and Research Establishments, and Certification Authorities. A total of thirteen papers were presented and a Round Table Discussion followed.

Icing has long been recognized as one of the more severe environmental conditions in which an aircraft might have to operate, and while systems have been developed to protect both airframe and engine from the effects of icing, for some aircraft avoidance is still the best and only protection. Of course if a military aircraft or helicopter is required to avoid icing conditions as part of its operating procedure its role will be severely limited. It becomes very important therefore, to identify the icing conditions the aircraft might encounter in service and then provide the designer with the necessary data to design, develop, test, and certify suitable protective systems. The purpose of the meeting was to bring together icing specialists to review the state of the art and hence to assess the need for further research and facilities for icing testing.

2. DISCUSSION OF CONTRIBUTIONS

The papers are referenced, at the end of this report, in their order of presentation at the conference. A review of the papers presented at each session and comments on the question and answer period, which followed each paper, are given below.

2.1 REQUIREMENTS

Three papers were presented in this session. Stallabrass[1*] discussed results of a study at NRC, Ottawa on snow concentration measurements, Gayet and Soulage[2] showed results of a study on the physics of icing clouds in France and North Africa, and Vath[3] summarized and compared the existing engine icing certification requirements.

Because snow crystals do not adhere to the cold surfaces on which they may impinge, aircraft flight in snow presents few problems and consequently little research has been done on the physics of snow in the atmosphere. However, for engine installations which require inlet ducting, as is often the case for helicopters, ingested snow can accumulate, melt, and refreeze to present a serious problem.

Stallabrass[1], with a relatively simple sampling device, measured snow concentrations, at a single location in Ottawa, over a period of six winters. A relationship between measured snow concentration and visibility was established and it was shown that different ice crystal types had little effect on this relationship. Further work, using an automatic sampling device, will provide more data and should the visibility data be confirmed, then snow concentration data for any location may be derived and provide an excellent basis for defining engine test requirements for snow. The author also studied the relationship between concentration/precipitation rate and concentration/air temperature and found no definite relationship.

The validity of the snow concentration data at altitude was questioned, however it was reasoned that except for minor flurry activity the variation up to cloud base should be minimal.

Gayet and Soulage[2] presented data from 117 flights in icing clouds, 87 of the cumuliform type and 30 stratiform. Droplet size and liquid water content (LWC) were measured with the Knollenberg apparatus and total liquid water content using an apparatus by Ruskin. Volumetric mean droplet diameters of the order of 1000 micron were measured in both stratiform and cumuliform clouds and local liquid water contents of up to 19 gm/m^3 were also reported. The authors also provided a comparison of their results with those of FAR Part 25 Appendix C and concluded that their measurements exceeded the FAR values both in terms of L.W.C. and droplet size. The differences were attributed to the type of instrumentation used for the measurements.

In the discussion it was pointed out that the FAR values used for comparison were those for FAR clouds of standard horizontal extent of 3 miles for cumuliform clouds and 20 miles for stratiform clouds and therefore do not present a valid comparison. Furthermore the statistical data on which the FAR conditions were initially based were from 3200 icing cloud encounters (NASA 1-19-59E) during routine in-service flight and in no way represent maximum possible conditions. In fact, NACA TN 1855 which is the basis for the Appendix C conditions suggests LWC of the order of 6 gm/m^3 for short durations. On the other hand, none of data suggested the existence of as large droplet sizes as seen in the Gayet and Soulage study.

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* Papers presented are listed at the end of this report.

Vath[3] in his summary of the various centification requirements noted that all were based on the meteorological data presented in FAR Part 25 Appendix C and he concluded that the differences were so small that it should be possible to have universal requirements. In the comparison however the conditions outlined in FAA AC-20-73, which are advisory in nature, were considered to be regulatory. The American requirements are in fact specified in FAR 33.68 and unlike the European requirements are very general: "Operate throughout its flight power range......in continuous maximum and intermittent maximum icing conditions as defined in Appendix C of Part....." The actual certification test program is arrived at by negotiation between the manufacturer and the certifying region and can be different for various engines. This philosophy argues against a universal requirement but does offer advantages since different engines can have different missions and certain anti-icing systems might require special attention.

Bender[12] illustrated clearly the peculiar nature of helicopter engine anti-icing which stressed the need for definite test requirements for snow. Grabe and Tedstone[13] described the very specific requirements of an inertial separator anti-icing system where droplet size is a dominant parameter and therefore suggested the importance of testing at various droplet sizes.

2.2 FACILITIES AND INSTRUMENTATION

Swift[4] and Bongrand[5] gave detailed descriptions of the icing test facilities available at the NGTE, UK and CEPr, France. At both establishments a concerted effort has been made to upgrade the facilities to provide a better "real time" measurement of the icing parameters. The laborious "oil slide" technique, for droplet size measurement, continues to be used for calibration purposes but has been replaced with the Knollenberg apparatus for a "real time" display of droplet size. Measurement of spray nozzle water flow continues to be the primary method of measuring LWC, however, the CEPr have experimented with the Knollenberg and Ruskin apparatus and with the more classic rotating cylinder technique. The present state of the art does permit a control of both droplet size and LWC to within 10%.

The NGTE facility has the capacity to test the largest existing turbo-fan engines and full-scale aircraft components, such as a helicopter fuselage, over a wide range of altitude and flight conditions. The CEPr facility, while somewhat limited as to size of engines it can accommodate does provide the range of altitudes and flight conditions.

Hunt[6] described results of a mathematical model of droplet behaviour in a moving stream. Serious questions as to the extent of droplet evaporation and degree of supercooling are being investigated with some success. At the present level of technology, the author pointed out the generation of very large droplets (500 micron or greater) becomes impossible due to the instability of droplets in the presence of large shear forces.

Keller[7] reported on an outdoor free jet test facility used for the CFM56 engine certification tests. The facility incorporated "real time" control - measurement systems which provided LWC and droplet size conditions very close to the engine inlet plane. Measured LWC data were compared to the mathematical model described by Hunt[6] and excellent agreement was found.

There was discussion as to the relative merits of altitude and sea level facilities. It was agreed that altitude simulation is important if a true evaluation of engine operating behaviour in icing is necessary; however much preliminary and sometimes sufficient testing can be done at sea level. Of course altitude facilities are independent of the ambient atmospheric conditions and therefore offer complete flexibility with regards to the timing of an icing program.

2.3 EXPERIENCE

Ball and Prince[11] and Grabe and Tedstone[13] reported on certification tests of engines for fixed wing aircraft and while different approaches and test conditions were used to evaluate the various systems in all cases service experience has shown the present test facilities and requirements provide good and safe anti-icing systems. The general discussion was active on the point but the consensus was one of agreement. However, Bender[12] in his description of the B0105 helicopter certification program demonstrated that the facilities and requirements for properly testing helicopter engines leave much to be desired. To simulate rotor downwash effects an outdoor open spray rig (NRC, Ottawa) has to be used and it is difficult to provide controlled conditions with such a set up. Various attempts were made to generate snow but in the end natural snow had to be manually shovelled at the engine inlet.

Pfeifer[9] presented a very complete summary of background information, equations, and design charts to be used to evaluate the possible effects of icing on an engine, to determine the degree of ice protection required, and to design an appropriate system. The design philosophy proposed is apparently in general use and provides a conservative approach to the problem. Both verification tests and service experience have borne this out.

Ringer and Stallabrass[8], in response to the very specific demands of the helicopter with respect to ice detection have developed a probe which is both sensitive and robust.

Bongrand[10] presented an analysis and some positive test results to demonstrate the existence of similarity parameters which can be used for icing tests. These results are significant since it will permit the use of simplified models and facilities particularly for development of components.

From the discussions, what appeared to be missing in this session was quantitative information with regards to actual flight experience. There is no doubt that the systems in use are working well but there is little evidence available to provide a real evaluation of the design and testing techniques. One might speculate that designs are overly conservative or that fixed wing aircraft spend a lot less time in icing than is thought. If the latter is indeed true then there is a possible risk in applying the present knowledge to helicopter engines anti-icing which no doubt experience different icing conditions.

3. ROUND TABLE DISCUSSION

There was general agreement among the panel members that the present requirements for testing in supercooled water are adequate for fixed wing aircraft engines; service experience has shown this to be true. On the other hand, there are no real requirements for snow and this can no longer be ignored if all-weather helicopters are to be developed.

It was noted that the use of sophisticated instruments to accurately measure the physical properties of clouds has been demonstrated and that they should be applied to new research. Also the existence of large supercooled droplets in the atmosphere must now be accepted and considered, at least in the design phase.

There was no great criticism of the facilities available for testing fixed wing aircraft engines; however there was some doubt expressed as to the suitability of the helicopter test facilities. It was felt that a better definition of the needs of the helicopter has to be made before facilities are made available. At present the helicopter is limited in icing by other components (windscreen, rotor, etc.) and there appears to be no pressing need for engine requirements; however the time will come.

4. CONCLUSIONS AND RECOMMENDATIONS

Dr. Dunham, the Committee Chairman, in his opening remarks posed four basic questions and these were:

(1) Are the present requirements necessary and sufficient?

(2) Are we properly equipped to test for them?

(3) Can we measure what we need to measure in flight and in the test facilities?

(4) What research needs to be done?

These questions, with their answers, define well the future requirements.

For fixed wing aircraft, from the information presented, the answers to questions (1), (2), and (3) has to be yes, however, for helicopters because of the different operating conditions and missions the answer can only be maybe and the answers will have to come equally from research and from operating experience.

There appears to be no urgent need for new research into the meteorological icing conditions at altitude except perhaps to identify differences in the condition experienced in America, where most research has been done, and the rest of the world. Ground icing conditions, on the other hand, must be better understood.

The problems of helicopter engine anti-icing has been demonstrated to be a very special one and is probably best treated under the general subject of helicopter icing.

Should new research show that testing with very large droplets becomes a requirement the present facilities might prove to be inadequate since large droplets produced by static spray nozzles do not remain intact under the aerodynamic shear forces.

The shortcomings of the present methods of simulating snow are obvious and better techniques must be developed.

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15. Abstract

This Technical Evaluation Report on the Propulsion and Energetics 51st (A) Specialists' Meeting on Icing Testing for Aircraft Engines contains a survey of the thirteen papers presented, and of the discussions which followed each paper, as well as of the concluding Round Table Session, Conclusions are drawn and recommendations made regarding future work.

The papers presented at the meeting, together with the discussions, are published as AGARD Conference Proceedings CP 236 – Icing Testing for Aircraft Engines.

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